



## Peak Field in Superconducting Current Transformer

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### Introduction

Superconducting current transformer has been developed and built to supplement the cable splice testing at the Fermilab Short Sample Test Facility (SSTF) [1]. The transformer primary winding consists of 64 turns made of 1-mm NbTi strands, coated with polyamide insulation. The secondary winding consists of 1 turn made of 27 strand NbTi cable. Before the test, the secondary winding is spliced to a sample (Nb<sub>3</sub>Sn) cable, forming a closed loop for the current. Afterwards, the transformer is inserted inside the SSTF cryostat and the primary winding is energized with 1-kA current supply. Details of the transformer construction and testing procedures are described in [2].

This note describes a peak field analysis performed for the transformer primary and secondary windings.

### 1. Model description

Magnetic field in the current transformer was simulated using OPERA3D code. The primary and secondary windings were approximated by single turns, with the relevant dimensions. Current sharing between the cables in the splice area was not taken into account. Since the peak field point belongs to the beginning of the splice, where both cables still carry maximum current, this effect was negligibly small. Figure 1 shows the transformer 3D geometry.

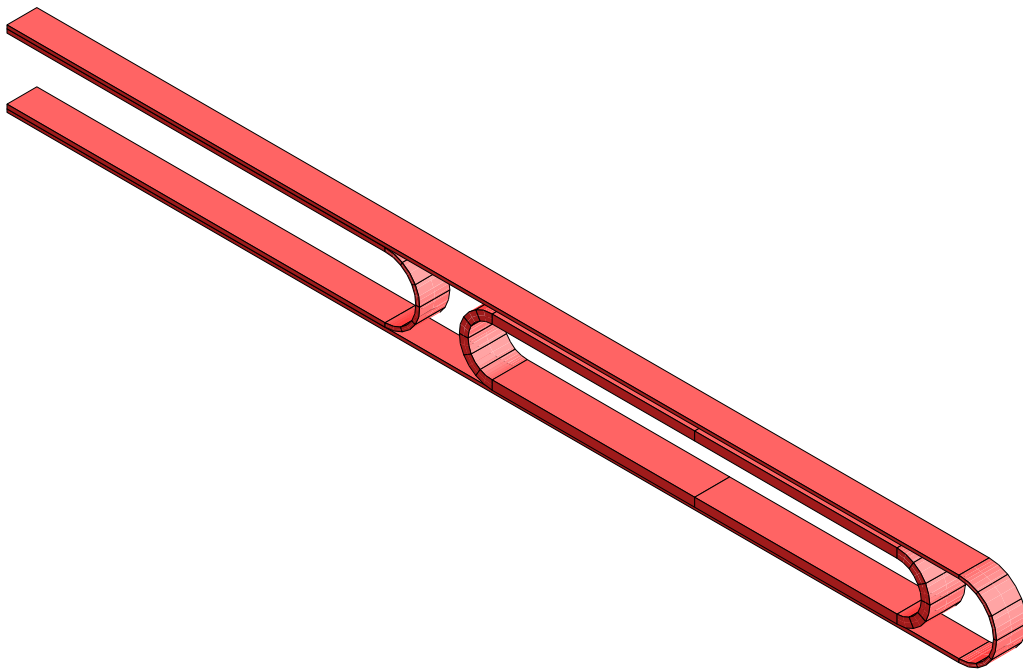


Figure 1. The current transformer geometry.

## 2. Simulation results

Operation of the transformer involves multiple changes of the current values and signs in both windings. Since there are no materials with non-linear magnetic properties near the region of interest – the field distribution is a linear function of the current. It gives possibility of representing the peak fields in terms of transfer functions, pertinent to different areas of the coils. Figure 2 shows the peak field normalized by the current in the secondary winding as function of the current ratio between primary and secondary windings (total current is given) and Table 1 summarizes the numerical values. Positive current ratio corresponds to the case, when currents in the primary and secondary coils are opposite (during the ramp-up) and the negative ratio corresponds to the same current direction (during the ramp down). Figure 3 shows the field distribution in the transformer longitudinal cross-section at  $N \cdot I_1 = I_2 = 20$  kA during the ramp-up.

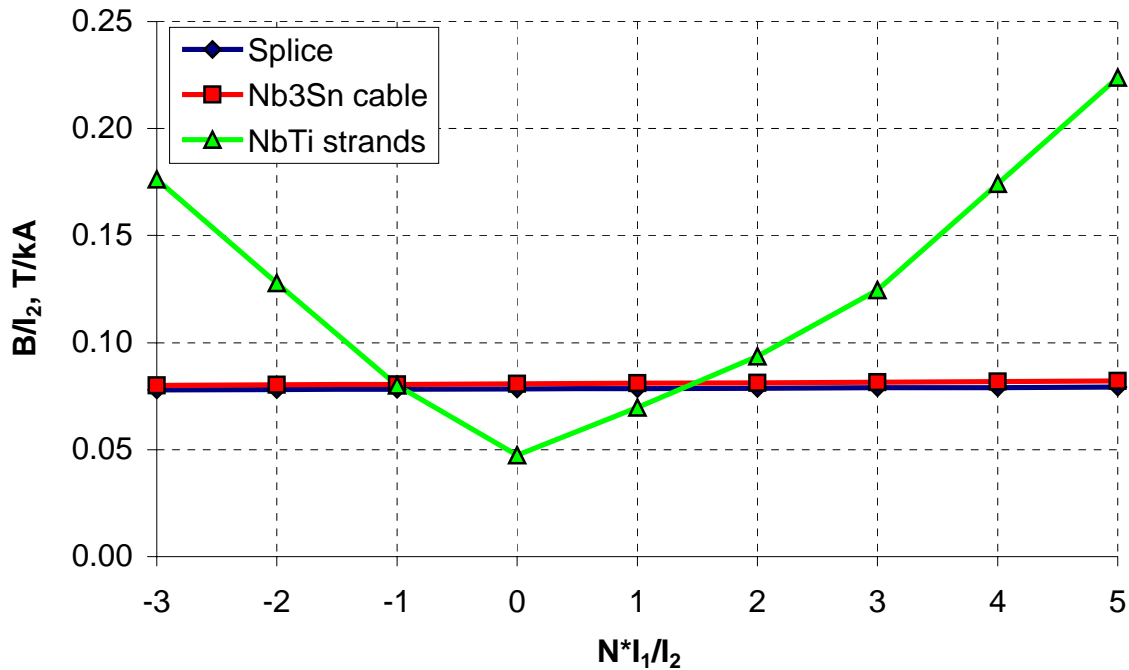


Figure 2. Normalized peak field in the transformer.

Table 1. Normalized peak field in the transformer.

$I_1/I_2$	$B_2/I_2$ , T/kA		
	Splice	Nb <sub>3</sub> Sn cable	NbTi strands
-3	0.0779	0.0800	0.1763
-2	0.0781	0.0803	0.1278
-1	0.0783	0.0805	0.0801
0	0.0784	0.0808	0.0474
1	0.0786	0.0811	0.0697
2	0.0787	0.0813	0.0937
3	0.0789	0.0816	0.1245
4	0.0793	0.0819	0.1741
5	0.0793	0.0821	0.2238

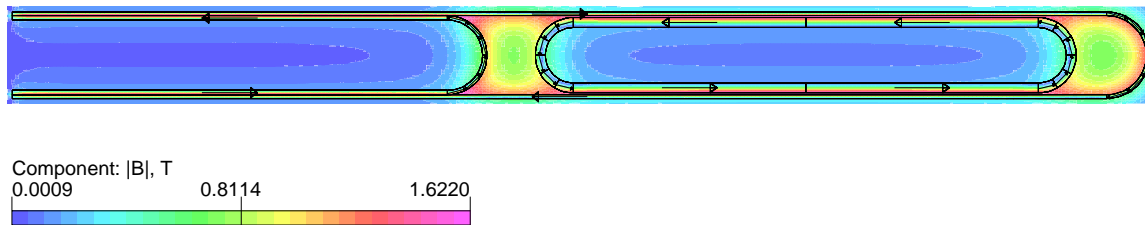


Figure 3. Field distribution in the transformer cross-section.

One can see that the normalized peak field in the splice and  $\text{Nb}_3\text{Sn}$  cable virtually does not depend on the current ratio. It explains by a significant distance between the primary winding and the relevant spots in the secondary winding (the first peak field point corresponds to beginning of the splice and the second one – to the place where both cables just merged together). Thus, it is possible to characterize the peak field in the  $\text{Nb}_3\text{Sn}$  cable and splice by  $B/I_2 = \text{const} = 0.08 \text{ T/kA}$ , which gives 1.6 T field for 20 kA cable current.

The normalized peak field ratio in the primary winding depends strongly on the current ratio. Changes in the slopes at  $N \cdot I_1/I_2$  of -1 and 3 explains by the shift of the peak field point from the outside to the inside surface of the primary coil.

The used data format is not contingent with representation of the peak field at  $I_2 = 0$ . This case was simulated separately and corresponds to  $B/(N \cdot I_1) = 0.0498 \text{ T/kA}$ . It allows estimation of the peak field for virtually any practically achievable combination of the primary and secondary currents.

In order to have possibility of association the cable tests using the transformer with the magnet quench performance, the field distribution was computed at the beginning of the splices in HFDA magnet series. The OPERA3D model used during this simulation is described in [3]. The ratio between the peak field and cable current stays virtually constant at large currents and equals to  $B/I_c = 0.052 \text{ T/kA}$ . About 20 % of this value is coming from the coil fringe field and the rest corresponds to the lead-generated self-field.

Thus, the cable current of 20 kA produces  $\sim 1 \text{ T}$  maximum field in the magnet splice, which is 60 % smaller than in the transformer splice at the same current. Therefore, the splice conditions in the transformer are conservative with respect to the magnet splice conditions.

## References:

- [1] E. Barzi, C. Boffo, J. Ozelis, Short Sample  $J_c$  Measurements at the SSTF, TD-98-057.
- [2] N.Andreev, E.Barzi, S.Bhashyam, C.Boffo, D.Chichili, S.Yadav, I.Terechkine, A.Zlobin, Superconducting Current Transformer for Testing  $\text{Nb}_3\text{Sn}$  Cable Splicing Technique, TD-02-014, April 10, 2002.
- [3] V.V. Kashikhin, Peak Field Definition in HFDA Magnet Series, TD-02-006, February 19, 2002.